UNIVERSITI PUTRA MALAYSIA

THD IMPROVEMENT FOR VARIABLE SPEED DRIVE USING SINGLE PHASE MULTILEVEL INVERTER

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BY

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Dedicated to my parents, lovely brothers and sisters

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement of the degree of Master of Science

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Chairman: Associate Professor Senan Mahmod, PhD

Faculty: Engineering

Low harmonic waveform is a very important requirement of the high power applications. Nowadays many researchers are focusing on new voltage source. Such voltage sources are formed by Cascade H-bridge Multilevel Inverter with low Total Harmonic Distortion (THD). A multilevel inverter has wide applications especially for High-Power Electrical Vehicle motor drive because they convert small DC voltage to high AC voltage. This study investigates the performance and discusses the features of transformer and transformer-less multilevel inverters. In order to generate sinusoidal wave with minimum total harmonic distortion, one approach has been adapted to calculate the conducting angles. Simple external circuit was employed to equalize the magnetic flux via each transformer which makes it more efficient in order of the manufacturability. All H-bridge will have the same specifications which enhance the modularity of the system. THD values have been measured experimentally and from

simulation results, the results show a good agreement with latest research. The experimental result has been compared with the simulation values, considerable difference have been notice because the effect of some factor such as the difference in components quality and the precise of the microcontroller. The PIC microcontroller was used to generate the gate signals and controlling the swapping circuit. The proposed circuits were simulated using Orcad/Pspice and experimental prototype was build as a drive for single phase induction motor based voltage / frequency method to show the validity of this system. Simulation of the diode clamped and transformer-less cascade multilevel inverter has been carried out to investigate their features.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBAIKAN JUMLAH HEROTAN HARMONIK UNTUK PEMBOLEHUBAH PEMACU MENGGUNAKAN PENUKAR BERBILANG PARAS SATU FASA

Oleh

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Gelombang harmonik rendah amat penting dalam aplikasi kuasa tinggi. Pada masa ini, para penyelidik memfokuskan penyelidikan tentang sumber tenaga baru yang terbentuk daripada Penukar Berbilang-paras Jejambat-H Melata dengan Jumlah Herotan Harmonik (THD). Penukar berbilang-paras mempunyai kegunaan yang meluas terutama untuk pemacu kenderaan motor elektrik berkuasa tinggi kerana ia boleh menukar voltan DC yang kecil kepada voltan AC yang lebih besar. Kajian ini mengkaji tentang tahap prestasi bagi transformer dan membincangkan ciri-ciri pada transformer dan transformer penukar berbilang-paras. Untuk menghasilkan gelombang sinus dengan jumlah herotan harmonik yang minima, satu kaedah pengiraan telah diadaptasi bagi mengira sudut pengaliran. Bagi meningkatkan kecekapan transformer untuk tujuan pengeluaran, litar luaran yang ringkas telah digunakan untuk menyeimbangkan flux magnetik melalui setiap transformer. Semua jejambat-H akan mempunyai spesifikasi yang sama bagi

memperbaiki pengubahsuaian sistem. Nilai THD telah diukur secara uji kaji dan keputusan simulasi menunjukkan persamaan dengan penemuan terkini. Keputusan ujikaji ini telah dibandingkan dengan nilai simulasi, dan terdapat beberapa perbezaan disebabkan oleh beberapa faktor seperti perbezaan kualiti komponen dan ketepatan pengawalmikro yang digunakan. Pengawalmikro PIC telah digunakan untuk menghasilkan isyarat masuk dan mengawal litar penukar. Litar ini telah disimulasi dengan menggunakan aturcara Orcad/Pspice, manakala prototaip ujikaji telah dibina sebagai pemacu motor satu-fasa berasaskan kaedah voltan/frekuensi untuk memperlihatkan kekuatan sistem ini. Bagi mengetahui tentang ciri-ciri yang ada, simulasi untuk pengapit diode dan aliran transformer penukar berbilang- paras telah dikaji.

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Last but certainly not least, I would like to deeply acknowledge my parents, for their untiring efforts in providing moral and financial assistance that inspired to finish this work.

I certify that an Examination Committee met on 6 July 2006 to conduct the final examination of Safoan. M.O. Alhalali on his Master of Science thesis entitled "Improvement of Total Harmonic Distortion for Variable Speed Drive using Single Phase Multilevel Inverter" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for equation and citations, which have been duly acknowledged also, declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

safoan

SAFOAN M. OALHALALI

Date: 23/8/06

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
ALU	Arithmetic and Logical Unit
ASD	Adjustable Speed Drive
CHMI	Cascade H-bridge Multilevel Inverter
CPU	Central Processing Unit
DC	Direct Current
DCMI	Diode Clamped Multilevel Inverter
DSP	Digital Signal Processing
EMI	Electromagnetic interface
EPROM	Erasable Programmable Read Only Memory
EV	Electrical Vehicle
FCMI	Flaying Capacitor Multilevel Inverter
FFT	Fast Fourier Transforms
GTO	Gate-Turn-Off Thyristor
HEV	High Power Electrical Vehicle
IC	Integrated Circuit
IGBT	Insulated Gate Bipolar Transistor
I/O	Input/Output
m_a	Modulation Index
MOSFET	Metal Oxide Silicon Field Effect Transistor

NPC	Neutral Point Clamped
PWM	Pulse Width Modulation
PC	Personal Computer
PIC	Programmable Integrated Chip
RAM	Random Access Memory
RMS	Root Mean Square
ROM	Read Only Memory
SDCS	Separate DC Sources
SPWM	Sinusoidal Pulse Width Modulation
SVM	Space Vector Method
THD	Total Harmonic Distortion
VAR	Volt-Ampere Reactive
VFI	Voltage –Fed Inverter
WDT	Watchdog Timer

CHAPTER I

INTRODUCTION

Low harmonic waveform is a very important requirement of the high power applications. Nowadays many researchers are focusing on new voltage source. Such voltage sources are formed by Cascade H-bridge Multilevel Inverter (CHMI) with low Total Harmonic Distortion (THD) [1]. A CHMI has emerged as new breed of power converters for high-power application options. The multilevel voltage source inverter typically synthesizes the staircase voltage wave from several levels of dc voltage. As the number of voltage levels on the input DC side increases, the output voltage adds more steps, which approaches low THD sinusoidal wave [2]. A CHMI has wide applications especially for High-Power Electrical Vehicle (HEV) motor drive because they convert small dc voltage to high ac voltage [3]. Five levels rectifier-inverter drive systems that has used some form of multilevel Pulse Width Modulation (PWM) as means to control the switching of the rectifier has lower dv/dt than that experienced in some two-levels PWM drives because switching is between several smaller voltage levels. However, the output voltage THD was reported to be 19.7% for a five-level PWM inverter without implementing output filters [4].

There are three main transformers-less types of multilevel inverters; Diode–Clamped Multilevel (DCMI) Inverters, Flying-Capacitor Multilevel (FCMI) Inverters, and CHMI. Unlike DCMI and FCMI, Transformers-less CHMI needs least number of components to achieve the same number of voltage levels.

1.1 Single Phase Induction Motor

In domestic application, SPIM are commonly used in dishwashers, washing machine, hermetic compressors, fans, pumps, draft inducers, etc. A truly variable speed operation from this motor with a wide range of speed and loads would help application designers to incorporate many new features in their products. It would also mean operation with high efficiency and better motor utilization. In industrial applications, three-phase induction motors have been used. However, in residential applications with small power, SPIM is preferred due to the greater availability of single-phase power [5].

A single-phase motor can only produce an alternating field: one that pulls first in one direction, then in the opposite as the polarity of the field switches. The major distinction between the different types of single-phase ac motors is how they go about starting the rotor in a particular direction such that the alternating field will produce rotary motion in desired direction. A device that introduces a phase-shifted magnetic field on one side of the rotor is usually employed for this purpose.

1.2 Problem Statements

The output waveforms of ideal inverters should be sinusoidal. However the waveforms in practical inverters are not sinusoidal and contain certain harmonics. For low and medium power applications, square wave voltages or quasi square wave voltages may be acceptable; and for high-power applications, low distorted sinusoidal waveforms are required. In this manner, A CHMI has wide applications especially for High-Power

Electrical Vehicle (HEV) motor drive because they convert small dc voltage to high ac voltage with low THD value [3]. Furthermore, the main disadvantages of the transformers-less CHMI is the need of separate source which makes the application of such topology more limited due to this problem. Furthermore, the output voltage will not exceed the sum of all DC sources.

1.3 Scope of Work

Multilevel power conversion has been receiving increased attention in the past few years for high power application [3]. The purpose of this research is to introduce and demonstrate a new design for CHMI in order enhance the function of this inverter and make it suitable for more application. The transformers have been used to cascade the H-bridges and avoid using multi DC sources to feed each H-bridge. In order to enhance the manufacturability of the transformer CHMI the research purpose a new switching scheme for transformer CHMI inverter by using swapping circuit; where, all of the transformers will have the same specification. Finally, the purposed inverter was used to control SPIM using V / F method based experimental prototype to validate the developed CHMI.

1.4 Aims and Objectives

This research introduces a new design for transformer CHMI, this inverter was developed based on the combination of utilizing transformer and swapping circuit. In this Manner, the manufacturability of the transformer CHMI will be enhanced and using multi DC sources will be avoided. The research objectives are:

1. Design and implementation of the developed design.
2. Enhance the manufacturability by utilizing the swapping circuit
3. Study and simulate the different type of the multilevel inverter and comparing the THD values with the developed design THD value.
4. Apply the developed design to control the SPIM with low THD value based V / F method

1.5 System Description

The CHMI was built by connecting four H-bridges inverter series with transformer. The microcontroller provides a set of square wave signals with certain delay between each other to provide the required voltage.

Since the power transfer is not equal in the power transformer, switching pattern-swapping scheme was designed to equalize power transferred via each transformer. Pattern-swapping circuit was built to avoid divergence of magnetizing force for the transformer connection because the difference of magnetic flux changes the rating of cascaded transformers. It results in the troublesomeness of the transformer design. Moreover, the current rating of each full bridge cell becomes different.

The spectrum analysis of the inverter output voltage was carried out experimentally by Fast Fourier transform (FFT) under math calculation in the Tekronix oscilloscope and compared with the simulation results. Simulation using Orcad/Pspice was carried out to simulate the system of three main types of multilevel inverter. Experimental and simulation results for proposed system were achieved with synthesizing the transformer as series connecter.

1.6 Structure of the Thesis

This thesis is organized in five chapters. The first chapter is to introduce the subject of the thesis and describes its organization. Chapter Two reviews the literature of the multilevel inverters for minimizing the THD. Chapter Three describes the design method of the hardware used in this work. Chapter Four presents Orcad/Pspice simulation result on PC and hardware results tested in the laboratory, the experimental result and discussion are also presented in this chapter. Finally, Chapter Five entails conclusion drawn from this work and recommendations for future work.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Multilevel power conversion has been receiving increased attention in the past few years for high power application [3]. Numerous topologies and modulation strategies have been introduced and studied extensively for utility and drive applications in the recent literature [6]. These inverters are suitable in high-voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum and attain higher voltage with limited maximum device rating. In this Voltage Source Inverter (VSI) based motor speed drive, there are mainly three different configurations and three branch configurations. In this chapter, firstly, the three main configurations will be analyzed with topics that directly related to the main target of these inverters. Secondly, some comparison between the different inverter and speed control topologies will be discussed.

2.2 Trend of Power Electronic Switch

The key components of the proposed inverter are the power semiconductor switches. As the main advantages of the proposed inverter are reducing the losses and stress upon the switch, therefore it is worthwhile to give some introduction to the trend of the modern power semiconductor devices applicable to CHMI mainly IGBT, GTO, and MOSFET.